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Preliminary analysis of ionosphere-corrected PPP-RTK user performance

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1. Introduction

The realization of the integer ambiguity resolution (IAR) enabled precise point positioning (PPP) method, the so-called **PPP-RTK**, is enabled by providing single-receiver PPP users with **satellite phase biases to recover the integerness of the user ambiguities**. Successful IAR can greatly reduce the solution convergence time. However, the unknown ionospheric delay parameters that are estimated by the PPP-RTK user (ionosphere-float model) do not allow for fast (or instantaneous) convergence to the centimeter level.

In this poster, we present a preliminary analysis on the improvement of PPP-RTK GPS dual-frequency user positioning performance **using precise ionospheric corrections**, which are expected to **greatly reduce the convergence time**. The ionospheric corrections used at the user level are determined by modeling PPP-RTK ionospheric slant delays computed from receivers of a regional network. The improvement of the PPP-IAR user performance is analyzed in terms of the required time to fix the integer ambiguities (TTFA) and the achieved convergence time to the 10 cm level.

2. PPP-RTK network system

The basis of the PPP-RTK network system is the **uncombined** GNSS code and carrier-phase observation equations:

$$E(p_{r,j}^s) = \rho_r^s + (dt_r - dt^s) + m_r^s \tau_r + \mu_j \iota_r^s + (d_{r,j} - d_{,j}^s)$$
$$E(\phi_{r,j}^s) = \rho_r^s + (dt_r - dt^s) + m_r^s \tau_r - \mu_j \iota_r^s + \lambda_j(\delta_{r,j} - \delta_{,j}^s + a_{r,j}^s)$$

Since not all the unknown parameters are unbiasedly estimable, we apply the S-system theory to eliminate the rank-deficiencies [1]. Assuming that precise orbits and clocks are used, the estimable parameters are:

$$\tilde{dt}_r = (dt_r + d_{r,\mathrm{IF}}) - (dt_p + d_{p,\mathrm{IF}}), \quad \forall r \neq p \qquad (p: \textit{ pivot rec./sat.})$$
$$\tilde{\iota}_r^s = \iota_r^s + d_{r,\mathrm{GF}} - d_{,\mathrm{GF}}^s, \quad \forall r, s \qquad (\mathrm{IF}: \textit{ ionosphere-free})$$
$$\tilde{\delta}_{r,j} = \left(\delta_{r,j} - \frac{1}{\lambda_j}[d_{r,\mathrm{IF}} - \mu_j d_{r,\mathrm{GF}}] + a_{r,j}^p\right) - \left(\delta_{p,j} - \frac{1}{\lambda_j}[d_{p,\mathrm{IF}} - \mu_j d_{p,\mathrm{GF}}] + a_{p,j}^p\right), \quad \forall j, r \neq p \qquad (\mathrm{GF}: \textit{ geometry-free})$$
$$\tilde{\delta}_{,j}^s = \left(\delta_{,j}^s - \frac{1}{\lambda_j}[d_{,\mathrm{IF}}^s - \mu_j d_{,\mathrm{GF}}^s]\right) - \left(\delta_{p,j} - \frac{1}{\lambda_j}[d_{p,\mathrm{IF}} - \mu_j d_{p,\mathrm{GF}}] + a_{p,j}^s\right), \quad \forall j, s$$
$$\tilde{a}_{r,j}^s = (a_{r,j}^s - a_{r,j}^p) - (a_{p,j}^s - a_{p,j}^p), \quad \forall j, r \neq p, s \neq p$$

3. PPP-RTK user system

The definition and estimability of the ionosphere-float PPP-RTK user parameters are the same as in the network component:

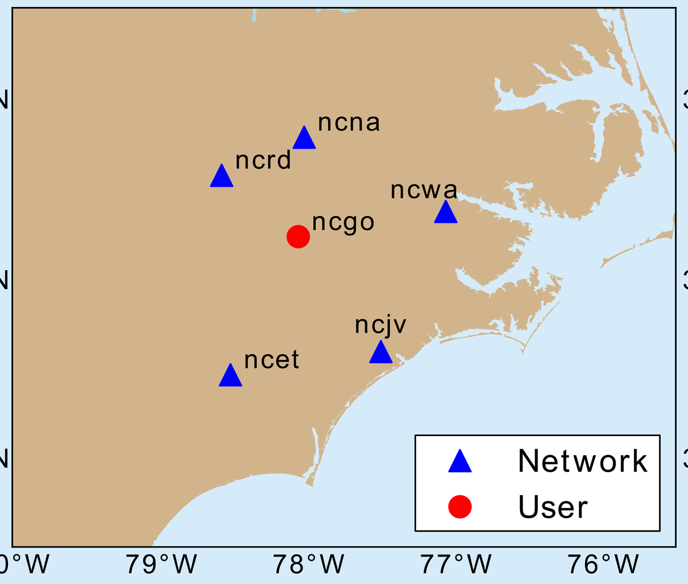
$$E(p_{u,j}^s + \tilde{dt}^s) = \rho_u^s + \tilde{dt}_u + m_u^s \tau_u + \mu_j \tilde{\iota}_u^s$$
$$E(\phi_{u,j}^s + \tilde{dt}^s + \lambda_j \tilde{\delta}_{,j}^s) = \rho_u^s + \tilde{dt}_u + m_u^s \tau_u - \mu_j \tilde{\iota}_u^s + \lambda_j(\tilde{\delta}_{u,j} + \tilde{a}_{u,j}^s)$$

The user phase ambiguities are now double-differenced and therefore **integer**.

If ionospheric corrections are provided to the user, the **receiver code bias parameter** of the user becomes estimable.

4. Data – Processing strategy

For the network and user processing, a network in US with the **largest inter-station distance being ~170 km** was processed for 24 hours on February 15, 2014. **Dual-frequency GPS-only** 30 s data are used for the processing with an elevation mask of 10 degrees.

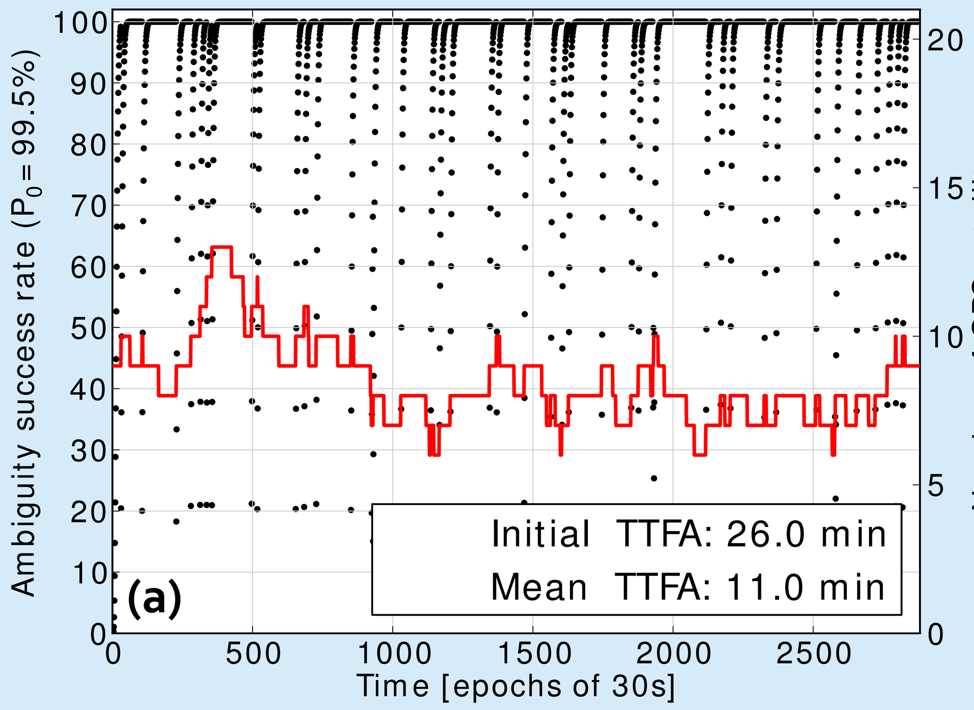


- Meas. noise at zenith: 30cm / 3mm for code / phase
- Parameter estimation using **Kalman filter**
- Full integer ambiguity resolution using **LAMBDA** [2]
- **User-specific ionospheric slant delays are determined** using the least-squares collocation [3] and the best linear unbiased prediction model [4].

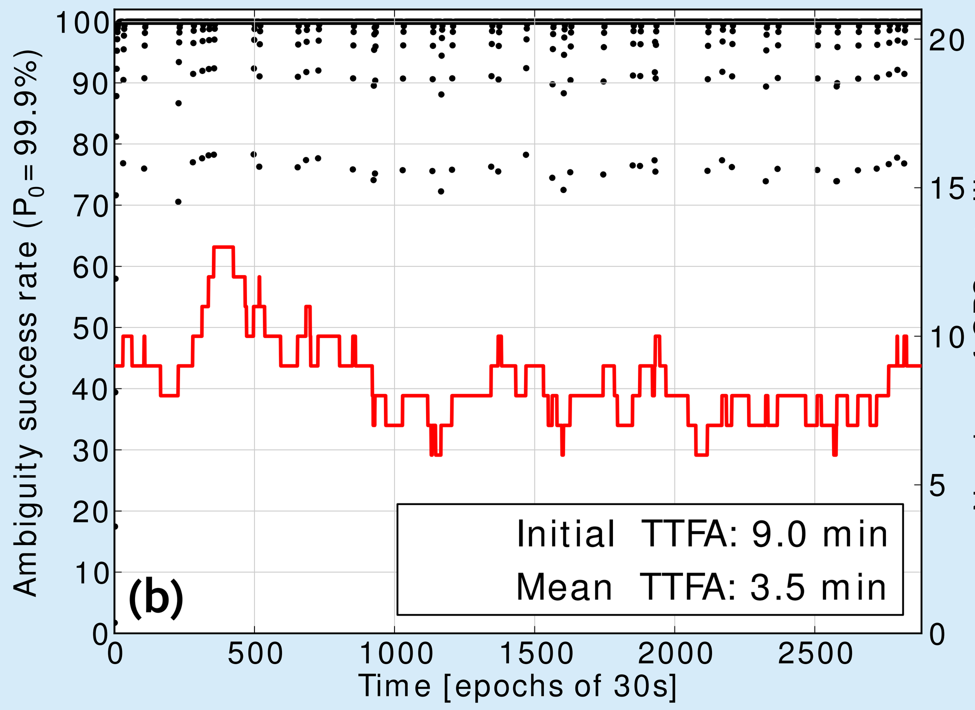
5. Results

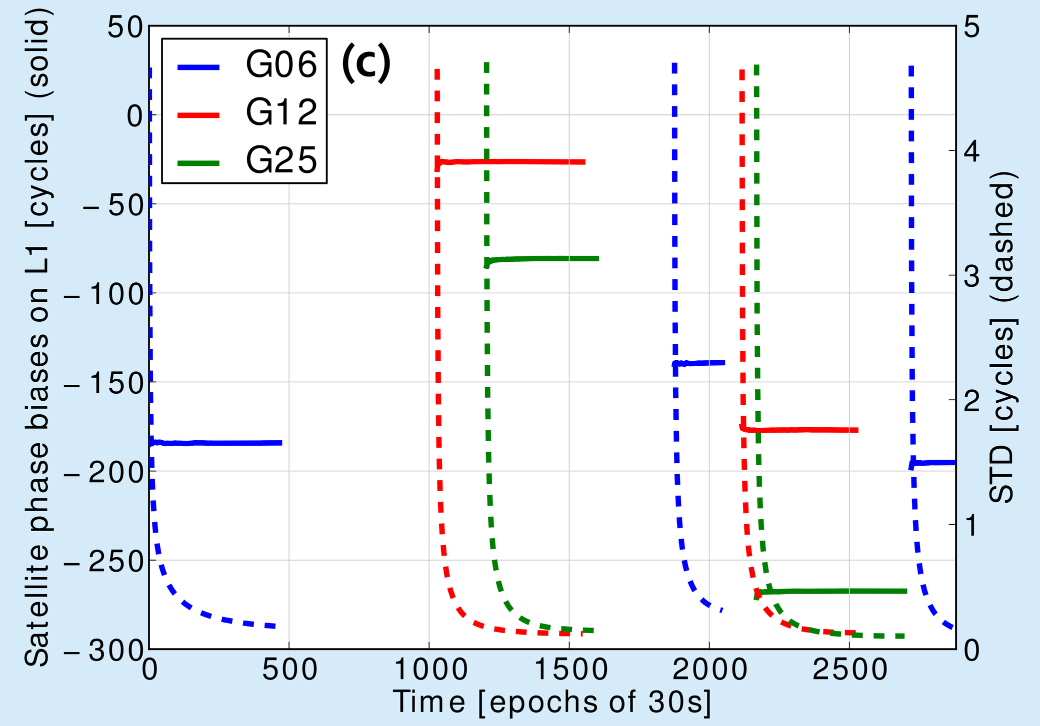
- When precise ionospheric corrections are provided to the user, **the model becomes stronger** than before leading to **more precise phase ambiguities** and, therefore, to higher ambiguity success rates and **shorter TTFAs**, see (a) and (b).
- The quite stable satellite phase biases, see (c), allow for realizing PPP-RTK. When **ionospheric corrections** are further used, the **convergence time** drops to **only 9 minutes**, see (d).
- The estimable **receiver code bias** shows a **stability over time**, with its daily variation not exceeding 20 cm, see (e).

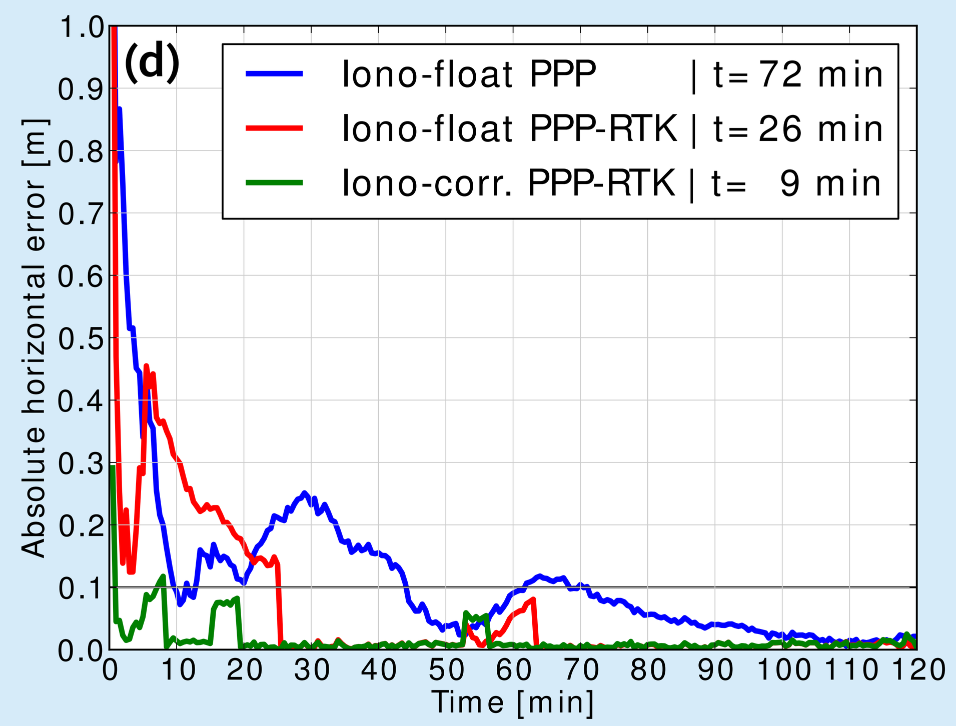
Ionosphere-float PPP-RTK user

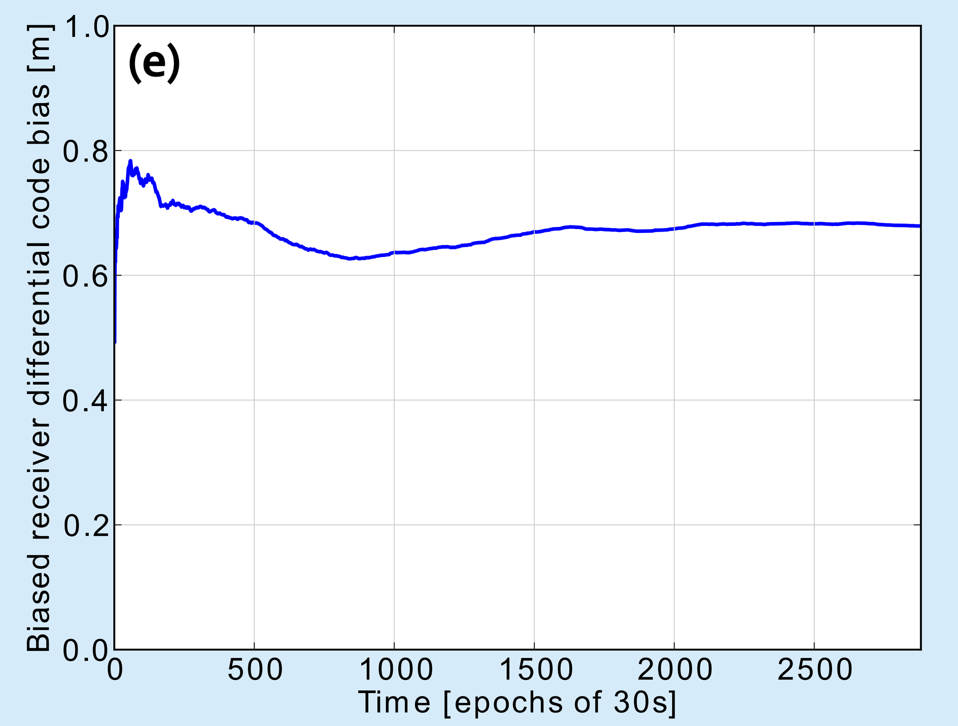


Ionosphere-corrected PPP-RTK user









6. Conclusions

- The **ionosphere-float model is weak in terms of IAR** due to the increased number of unknown parameters.
- **Precise ionospheric corrections** can significantly reduce the convergence time.

Outlook: A large number of sample data will be processed to infer the **distribution of the achieved convergence times**, due to the **random nature of the GNSS data**.

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